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River water quality in the Finnish Eurowaternet

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The Finnish Eurowaternet monitoring network includes about 200 river sites that are among the northernmost in the European Eurowaternet monitoring network. Their water quality was investigated using the medians of physico-chemical parameters (total phosphorus, total nitrogen, dissolved oxygen saturation percentage, pH, alkalinity, chemical oxygen demand, colour, electrical conductivity, total suspended solids, turbidity), hygienic indicator bacteria and trace metals (iron, zinc, nickel, chromium, copper, cadmium, arsenic, lead and mercury) calculated for the period 1998–2002. The river water quality was poorest in the south, improved towards the north and was best above the Arctic Circle. In addition it varied in the east–west direction being poorest in the west and best in the east. In the south population density is higher, there is more industry, arable land, agriculture and animal husbandry, which explain water quality differences. On a European scale the majority of the Finnish rivers, particularly those in the north, are rather unpolluted.

Introduction

Water quality of European rivers is monitored in the Eurowaternet monitoring network consisting of national networks established on common principles (European Environment Agency 1996). Its objective is to produce reliable and comparable information about the water quality of European waters. In 2004 the number of river sites in the whole Eurowaternet monitoring network was about 3400. The monitoring data gathered by the national networks are annually delivered to the European Environment Agency, where they are analysed, assessed and published (e.g. European Environment Agency 2005). The water quality monitoring programme required by the Water Framework Directive (European Parliament and Council Directive 2000) will partly be based on the national Eurowaternet monitoring networks.

The Finnish Eurowaternet monitoring network for lakes and rivers was started in 2000 (Niemi *et al*. 2001a). The river network includes 196 river sites distributed throughout the country. The network includes different types of monitoring stations (i) reference stations representing waters that are close to natural background conditions and only minimally affected by human impacts, (ii) representative stations reflecting the general quality of the waters within the area where they are located, and (iii) impact stations affected by loading e.g. due to municipal or industrial wastewaters, diffuse loading, fish farming, peat mining, etc. The rivers are regularly monitored and the data gathered are stored in the information system of the Finnish Environment Institute (Niemi 2006). Although the network consists of all types of sites it is not a group of randomly sampled rivers from the country, as it includes a large proportion of impacted sites established in the early 1960s. The network therefore probably includes more impacted river sites than were found in an equal number of randomly sampled rivers from Finnish territory. The number of smaller rivers or brooks is probably underestimated in the network. However, the network gives a general view of the river water quality of the country.

The Finnish Eurowaternet rivers are situated in the very north of the whole Eurowaternet monitoring network. They are scattered over a distance of over 1000 kilometres reaching from the relatively mild climate of southern Finland to severe climatic conditions above the Arctic Circle. This distance creates a south–north gradient in several respects. Climatic conditions e.g. temperature, period of ice cover, hydrological phenomena and land use vary from south to north. The land cover of Finland was mapped as a part of the European CORINE 2000 Land Cover Project (Finnish Environment Institute 2005a). This map shows that the land cover of the country is dominated by forests, lakes, rivers and locally by marshlands. The proportion of marshlands is high, approximately 30% of the area of the country. In the entire country about 9% of the land area is used for agriculture, concentrated mostly in the south and west. Population density is highest in the south (133 inhabitants km^{-2}) and lowest in the northernmost province (2 inhabitants km^{-2}). Percentage of agricultural fields, point-source and diffuse loading and other human impacts are prominent in the south, whereas the northern rivers are close to natural background conditions. However, even the northernmost rivers are affected by long-range atmospheric pollutants (AMAP 1998). The gradual change of these factors from south to north is likely to be reflected in the water quality of rivers.

Examples of earlier studies of the water quality and material budgets of Finnish rivers are: physico-chemical river water quality (Niemi 1998), bacteriological quality of rivers and lakes (Niemi *et al*. 1997, Niemi and Niemi 2000), water quality trends (Räike *et al*. 2003, Niemi *et al*. 2004, Mitikka *et al*. 2004, Ekholm and Mitikka 2006) and material balances of rivers (Pitkänen 1994, Kauppila and Koskiaho 2003). An overview of the state of Finnish inland and coastal waters was presented by Eloranta (2004). The lakes in the Finnish Eurowaternet were investigated by Mitikka and Ekholm (2003). In some of these publications a selection of Eurowaternet rivers, particularly those discharging to the Baltic Sea, has been investigated. However, the water quality of national Eurowaternet rivers has not been investigated as a whole.

Materials and methods

Water quality data of the 196 river sites were taken from the information system of the Finnish Environment Institute. Since the 1960s this cumulative information system has gathered water quality data, currently amounting to about 21 million results of water analyses from some 61 000 sampling sites. As the objective was to obtain an overall picture of the water quality in the country, the names and coordinates of individual river sites are not presented here. The sites are with few exceptions identical to those presented by Niemi *et al*. (2001b). For regional comparison of rivers the country was divided into southern, central and northern Finland (Fig. 1).

The sites are normally sampled 4–20 times a year and are analysed at the most for about 50 parameters. Not all rivers are analysed for all the variables. Sampling frequencies and analyses carried out in river sites are explained in more detail in Niemi *et al*. (2001b). The number of measurements for the whole period 1998–2002 varied from about 20 to 100. The largest rivers discharging to the Baltic Sea are sampled most frequently — at least 13 times a year — and some rivers impacted by agriculture 20 times a year.

The parameters investigated were physicochemical parameters (total phosphorus, total nitrogen, dissolved oxygen percentage, pH, alkalinity, chemical oxygen demand, colour, conductivity, total suspended solids turbidity), hygienic indicator bacteria (faecal enterococci) and trace metals (iron, zinc, nickel, chromium, copper, cadmium, arsenic, lead and mercury). Median concentrations of these parameters were calculated for the period 1998–2002. The use of medians levels out annual variations and reflects the general state of the river water quality. Medians were used instead of means, because high transient fluctuations in concentrations do not have such a great influence on medians as on means. The method does not include assumptions concerning the statistical distribution of the variables.

Sampling and chemical analyses have been carried out by the laboratories of the Environmental Authorities. The laboratories of the Environmental Authorities include one Research Laboratory of the Finnish Environment Institute in Helsinki and regional laboratories in different parts of the country. The Research laboratory is a national reference laboratory for chemical analyses. The Research Laboratory coordinates and supervises the activities of the national laboratories responsible for chemical analyses of environmental samples, namely the laboratories of the Environmental Authorities and other laboratories, by organizing intercalibrations of analytical methods. The majority of the laboratories involved in the environmental monitoring have accredited analytical methods. Certification of the persons in charge of sampling is carried out according to international recommendations. International standard methods are used. Consequently the produced data is comparable.

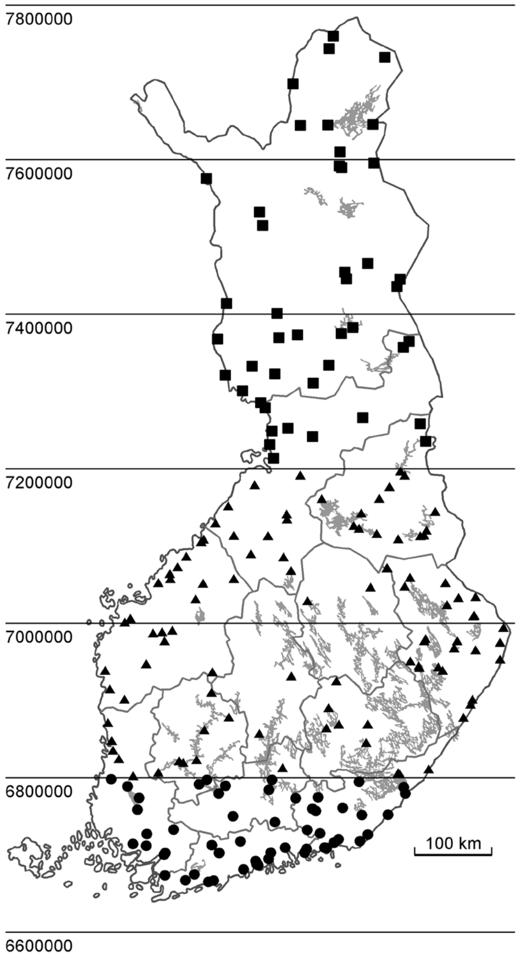

Fig. 1. The Finnish Eurowaternet river sites with north coordinates 660000 etc. (Finnish National Coordinate System) marked. River sites situated in southern Finland are marked with a circle, those in central Finland with a triangle and those in northern Finland with a square. The national coordinates expressed in brackets as WGS84(dm) are: 6600000 (5927.95), 6800000 (6115.44), 7000000 (6302.87), 7200000 (6450.24), 7400000 (6637.55), 7600000 (6824.78) and 7800000 (7011.93).

Results and discussion

Physico-chemical parameters

Overview

Median concentrations of physico-chemical parameters were calculated from the data of 1998–2002 (Figs. 2 and 3). River water quality showed a consistent south–north gradient, being poorest in the south and best in the north. Rivers in central Finland fell, with some exceptions, between these boundaries. In the rivers of southern Finland most parameters indicated poor river water quality. The highest median concentrations, e.g. those of total phosphorus, total nitrogen, alkalinity, suspended solids, turbidity and faecal enterococci were found in southern rivers. The rivers of central Finland generally had better water quality than those of the south. However, in the rivers in eastern parts of central Finland the values of chemical oxygen demand and colour were higher and the pH lower than in other rivers. The rivers situated farthest north above the Arctic Circle had the best water quality, being as close to natural background conditions as is possible anywhere in Europe.

As well as in the south–north direction the water quality also varied in the west–east direc-

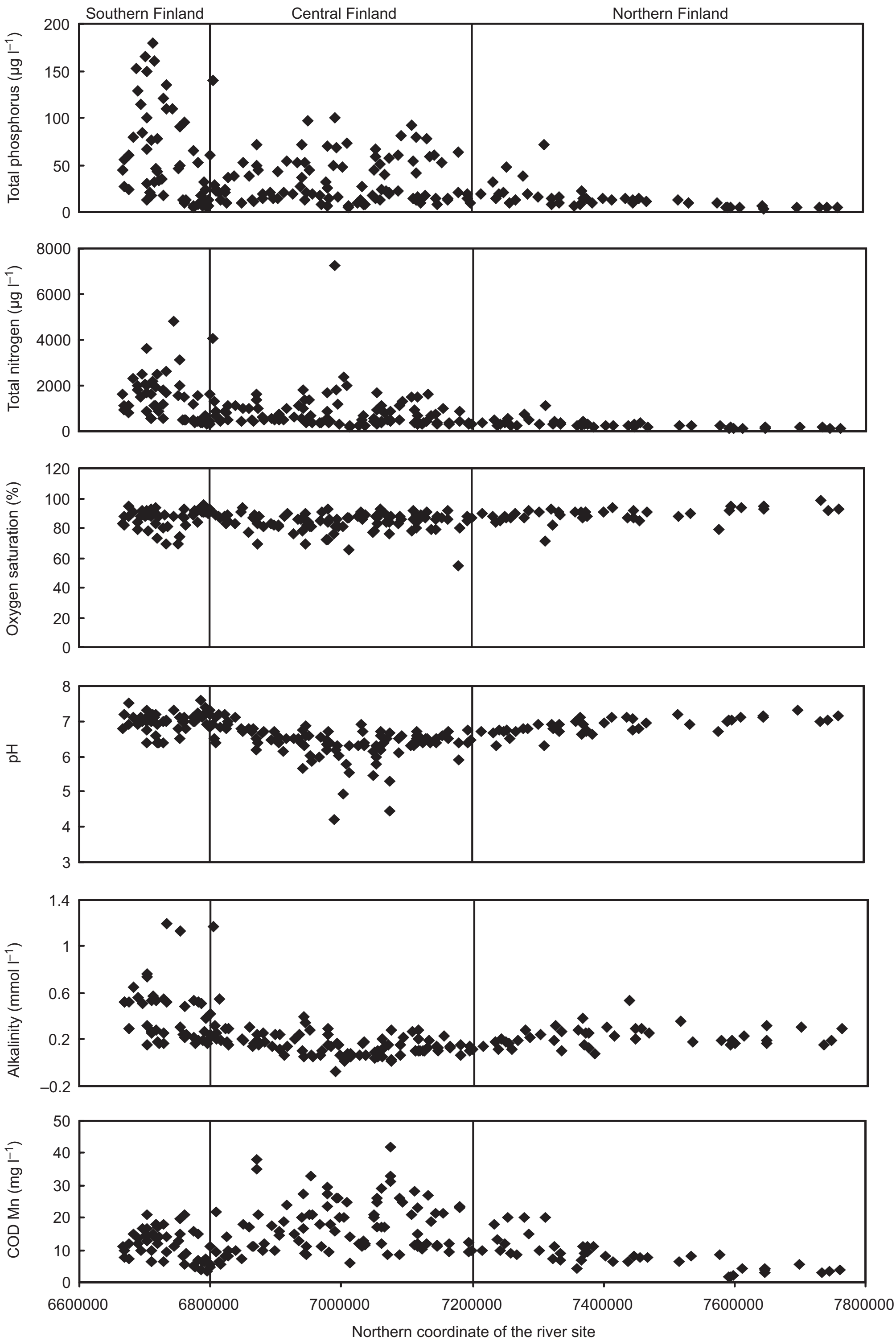

Fig. 2. Median concentrations of total phosphorus, total nitrogen, oxygen saturation percentage, pH, alkalinity and chemical oxygen demand for the period 1998–2002. River sites arranged from south to north by the north coordinates (*see* Fig. 1).

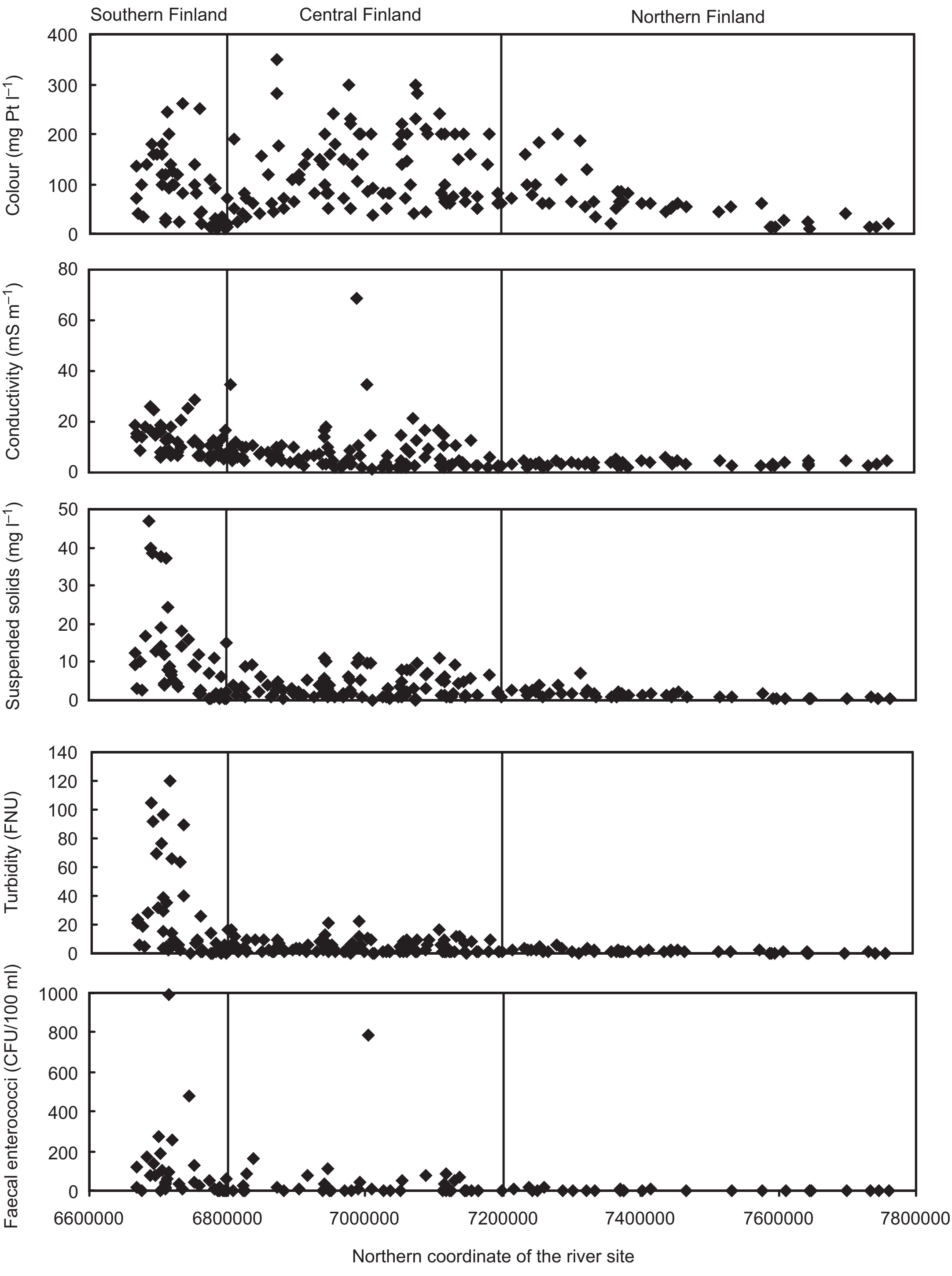

Fig. 3. Median concentrations of colour, conductivity, total suspended solids, turbidity, and faecal enterococci for the period 1998–2002. Sites arranged as in Fig. 2. Coordinate system as in Fig. 1.

tion within southern, central and northern Finland. This variation inside the areas was greatest in southern Finland (e.g. total phosphorus, total suspended solids and turbidity) and in central Finland (e.g. chemical oxygen demand and colour). A closer examination of the data revealed that the rivers with best water quality, often comparable to that found in the northern rivers, were situated in the eastern parts of these three regions. This variation is also reflected in the water quality classification of all inland waters carried out according to national criteria (Vuoristo 1998, Finnish Environment Institute 2005b).

The national Eurowaternet monitoring network is not a random statistical sample of Finnish rivers. Therefore the overall picture it provides about river water quality is probably poorer than the average quality of Finnish rivers, if randomly sampled. The Eurowaternet rivers probably represent both the best (northern rivers) and the poorest (impacted sites in the south) water quality found in Finnish rivers (with the exception of the sites close to discharge areas of wastewater treatment plants), and reflect the regional variation of river water quality.

Assessment by parameters

Total phosphorus

Phosphorus is a fundamental nutrient in aquatic ecosystems and a primary factor in the eutrophication of waters. In Finnish inland waters it is practically always a limiting nutrient (Pietiläinen 1997). Its main sources are municipal and industrial wastewaters and diffuse loading from agricultural fields or leaching from other soils. Consequently, high phosphorus concentrations indicate potential eutrophication with detrimental consequences such as increase in turbidity, oxygen depletion and excessive algal growth.

Total median phosphorus concentrations were highest in the rivers of southern Finland and fluctuated most in those of southern and central Finland. In the rivers of northern Finland variations were small, particularly in the very north. The highest and lowest individual medians were: southern Finland 180 μg l^{-1} and 4 μg l^{-1}, central Finland 140 μg l^{-1} and 5 μg l^{-1} and northern Finland 72 μg l^{-1} and 3 μg l^{-1}. In 13 river sites the median exceeded 100 μg l^{-1}.

Total nitrogen

Total nitrogen in water consists of dissolved nitrogen (inorganic and organic) and particulate nitrogen (organic and inorganic), minus nitrogen as gas. Phytoplankton and bacteria affect the dissolved inorganic nitrogen content. Decomposition of organic material produces dissolved organic and particulate organic nitrogen to water. Sources of nitrogen include e.g. wastewaters, diffuse loading particularly from agricultural fields and erosion that increases particulate inorganic nitrogen concentrations. Nitrogen concentrations of waters are decreased e.g. by bacterial denitrification.

Total median nitrogen concentrations varied most in the rivers of southern Finland. The medians were lowest and most stable in the northern rivers. Total nitrogen medians varied less than those of total phosphorus. The highest and lowest individual medians were: southern Finland 4800 μg l^{-1} and 340 μg l^{-1}, central Finland 7250 μg l^{-1} and 260 μg l^{-1} and northern Finland 1127 μg l^{-1} and 150 μg l^{-1}. In 16 river sites the median exceeded 2000 μg l^{-1}.

Oxygen saturation percentage

Oxygen is of fundamental importance in regulating aquatic life. The solubility of oxygen in water is proportional to the partial pressure in the atmosphere and decreases nonlinearly with increasing temperature. In addition primary production produces oxygen to water, whereas decomposition of organic matter consumes it. In the northern Finnish water bodies decomposition of organic matter can lead to oxygen deficit during the long ice-covered season, which lasts about 3–4 months in the south and about 6–7 months in the north. Oxygen saturation percentage is a measure of how much oxygen of the maximum amount that can be dissolved in the prevailing physical conditions is actually present in the water. In some conditions e.g. in eutrophic waters with intensive primary production the percentage can exceed 100%, but be much lower at night. The median oxygen saturation percentage does not indicate the occasional low concentrations that can be critical e.g. for fish, although it provides an overall picture of the oxygen conditions in rivers.

Median oxygen concentrations were relatively high in all rivers. There was a general tendency towards higher oxygen saturation percentage in the northern rivers. The highest and lowest individual median oxygen saturation percentages were: southern Finland 96% and 69%, central Finland 94% and 55% and northern Finland 99% and 72%. In 28 river sites the medians were less than 80%.

pH

Finnish waters are rich with acid humic substances and consequently pH values are often below 7. Median pH values of rivers were around 7 in southern Finland, clearly below 7 in central Finland with occasional very low values and close to 7 in the north. The lowest median values are mainly due to soil properties typical of the coastal areas in central Finland (bogs, sulphate soils). The highest and lowest individual median pH values were: southern Finland 7.6 and 6.6, central Finland 7.2 and 4.2 and northern Finland 7.3 and 6.3. In 13 river sites the median was below 6.

Alkalinity

Alkalinity or buffering capacity prevents the water pH from becoming too acid and adds carbon to water. It tends to stabilize water at pH levels around 7. Very low pH values (pH < 5) can cause harmful conditions for aquatic life. Highest alkalinity medians and highest variations were found in the rivers of southern Finland. In the rivers of other parts of the country alkalinity medians oscillated around 0.2 mmol l^{-1}, in central Finland somewhat below this value. The highest and lowest individual alkalinity medians were: southern Finland 1.2 mmol l^{-1} and 0.16 mmol l^{-1}, central Finland 1.2 mmol l^{-1} and –0.076 mmol l^{-1} and northern Finland 0.54 mmol l^{-1} and 0.08 mmol l^{-1}.

Chemical oxygen demand

The analysis of chemical oxygen demand (COD) is used to estimate the amount of organic matter in water. It is a measurement of the oxygen equivalent of the materials present in the water subject to oxidation by a strong chemical oxidant. In other words COD is the amount of oxygen that is required to degrade the organic compounds in water. The higher the COD value of water, the more oxygen the materials in water extract from water bodies. COD measures the oxygen demand to digest all the organic matter, whereas biochemical oxygen demand measures the portion of organic matter that can be oxidized by microbiological processes.

The COD medians were highest in the rivers of central Finland and lowest in the northern rivers. The high median values are mainly due to soil properties typical of the coastal areas of central Finland, the same factors that produce high pH values, e.g. high content of humic materials and sulphate soils. The highest and lowest values were: southern Finland 21 mg l^{-1} and 3.6 mg l^{-1}, central Finland 42 mg l^{-1} and 5.9 mg l^{-1} and northern Finland 20 mg l^{-1} and 1.6 mg l^{-1}. In 40 river sites the median COD exceeded 20 mg l^{-1}, and practically all these sites were in central Finland.

Colour

Colour indicates the concentrations of dissolved and suspended materials in water. It is determined by comparing a water sample with a known concentration of coloured solution e.g. the platinum-cobalt method. Factors that contribute to colour include naturally occurring metallic ions, particularly iron and manganese, humus and other materials discharged from marshlands, plankton, and municipal and industrial wastewaters.

The median colour values of rivers varied widely. The rivers with highest medians were situated in southern and central Finland and in the southern part of northern Finland. However, these areas also included rivers with low medians, mainly located in the eastern parts of the three regions. Variations in medians were pronounced in central Finland, where the proportion of marshlands of the river drainage basins is great and humic materials are discharged to waters resulting in high colour values. The highest and lowest medians were: southern Finland 260 mg Pt l^{-1} and 10 Pt l^{-1}, central Finland 350 Pt l^{-1} and 23 Pt $l^{-1}$and northern Finland 200 Pt l^{-1} and 10 Pt l^{-1}. In 29 river sites the medians exceeded 200 Pt l^{-1}.

Electrical conductivity

Conductivity is the ability of water to transmit an electric current. It depends on the presence of ions, on their total concentration and on temperature. Solutions of most inorganic compounds are relatively good conductors. Organic compounds that do not dissociate in water conduct electricity only weakly or not at all. Factors that affect conductivity in natural waters are e.g. soils and geology of the drainage basin, sources of ions to waters (e.g. point and diffuse sources of wastewaters), intensive rain, snowmelt period and the use of de-icing salts used on Finnish roads in winter to prevent accidents due to slippery conditions.

Median conductivity values showed a decreasing tendency from south to north, with occasional high medians in central Finland. A cluster of high medians in the coastal rivers of central Finland was due to the same factors discussed above (bogs, sulphate soils). The highest and lowest individual medians were: southern Finland 29 mS m^{-1} and 5 mS m^{-1}, central Finland 69 mS m^{-1} and 1.6 mS m^{-1} and northern Finland 6.3 mS m^{-1} and 1.7 mS m^{-1}. In 24 river sites the median conductivity exceeded 15 mS m^{-1}.

Total suspended solids

Water contains solid materials in dissolved and suspended forms. They are determined by filtering a known volume of water sample through a tared glass-fibre filter, which is then dried at 105 °C and reweighed to calculate the weight of material captured on the filter. Total suspended solids provide a measure of the turbidity of the water. High concentrations of total suspended solids generally indicate productive waters.

Highest median concentrations of total suspended solids were in the rivers of southern Finland. The concentration consistently decreased towards the north. The highest and lowest median values of total suspended solids were: southern Finland 47 mg l^{-1} and 0.5 mg l^{-1}, central Finland 11 mg l^{-1} and 0.2 mg l^{-1} and northern Finland 7 mg l^{-1} and 0.25 mg l^{-1} . In 23 river sites the median concentration of total suspended solids exceeded 10 mg l^{-1}.

Turbidity

Turbidity is measured by passing light through the water and measuring the scattered light photometrically. Turbidity is caused by materials suspended in the water and consequently it is an indirect measurement of total suspended solids. Therefore, as expected, the median turbidity values followed closely those of total suspended solids. In 20 river sites the median turbidity exceeded 20 FNU.

Factors explaining river water quality

Regional differences in river water quality can be explained by several factors. In the south and south–west population density is higher, there is more industrial activity, more arable land and agriculture and animal husbandry is intensive. Consequently many rivers in the south are of poor quality. Rivers with good water quality in southern Finland tend to be situated in the eastern part of the area.

Often the water quality was poor in the rivers of the coastal areas of central Finland. Explaining factors can be found from geological characteristics of the region, land use and human impacts on the environment. The ancient Litorina Sea was one postglacial phase in the development of the present Baltic Sea. During its existence about 7000–3000 years ago it partly covered the areas that are now Finnish territory. At that time post-glacial clays were formed at the bottom of the Litorina Sea. Since then the land has risen and presently the coastline of this ancient sea is situated inland from the Finnish coast. Due to this common past most of the coastal areas once covered by the sea and the rivers flowing in these areas have many similar characteristics. Sulphate soils are typical of these low-lying lands once submerged under the water. The rivers are slowly flowing and have turbid waters due to their high clay content, which originates from the soils of drainage basins. The lake percentage of the drainage basins is lower than in the other parts of the country.

In coastal areas watercourse construction works have been carried out for decades for flood protection. As a result, partly because of excavation works and natural characteristics of the soil, high chemical oxygen demand and colour values, somewhat elevated conductivity values and low pH values were found in the coastal rivers of central Finland.

The rivers of central Finland that had better water quality tended to be located in the lake district in the eastern part of this region. In northern Finland the rivers were less polluted than in other parts of the country and the west–east water quality variation was less pronounced. In the very north human impacts are insignificant and the river quality is close to background conditions.

Hygienic indicator bacteria

Because of the large numbers of different waterborne organisms that are known to be pathogenic to humans, including bacteria, viruses and protozoa, it is impossible to monitor them all. Bacteria that normally occur in the faeces of humans and homoiothermic animals — faecal indicator bacteria — are therefore used to indicate faecal pollution and health risks associated with it. Of the faecal indicators the most common groups are coliform bacteria, especially *Escherichia coli*, and faecal enterococci. Bacterial numbers are generally expresses as a number, or more precisely as the number of colony forming units (CFU) per 100 ml of water.

The total number of bacterial enumerations available from all rivers was only about 100. Bacterial quality of the rivers was generally good. The median concentrations were low, with the exception of occasional high values in the rivers of southern and central Finland. The median concentrations varied between 1 and 1000 CFU/100 ml (Fig. 3). Although the level of bacterial pollution was relatively low, the results indicated that many of the rivers are subject to faecal pollution.

The highest and lowest median concentrations were: southern Finland 995 CFU/100 ml and 1 CFU/100 ml, central Finland 790 CFU/100 ml and 0 CFU/100 ml and northern Finland 16 CFU/100 ml and 0 CFU/100 ml. In 11 rivers bacteria were not detected. The northern rivers were the least polluted. In 13 river sites the median concentration exceeded 100 CFU/100 ml. Bacterial concentrations were highest in the rivers of the southern, south-western and western coastal areas, where population density and percentage of agricultural fields are higher than in other parts of the country. The regional distribution of hygienic indicator bacteria in Finnish inland waters has been investigated in more detail by Niemi and Niemi (2000).

Trace metals

Trace metals are introduced to the environment from both natural and anthropogenic sources. Natural sources include e.g. soil geology, weathering of the bedrock and retention processes in the catchments. Anthropogenic deposition increases natural concentrations.

Median concentrations of trace metals showed a gradient similar to those of physicochemical parameters; high medians in southern rivers and low in northern rivers (Fig. 4). The medians decreased in the following order: iron, zinc, nickel; chromium and copper were at the same level, followed by lead, arsenic, cadmium and mercury. Medians of zinc, cadmium and arsenic were highest in the rivers of central Finland, whereas those of chromium, copper and lead were highest in the rivers of the south. Medians of arsenic and cadmium were practically at the same level in all rivers, with occasional high cadmium medians in central Finland.

On the basis of Fig. 4 a total of 40 rivers with the highest medians of trace metals were selected. This was carried out by selecting first five rivers with the highest zinc medians, then five rivers with the highest nickel medians and

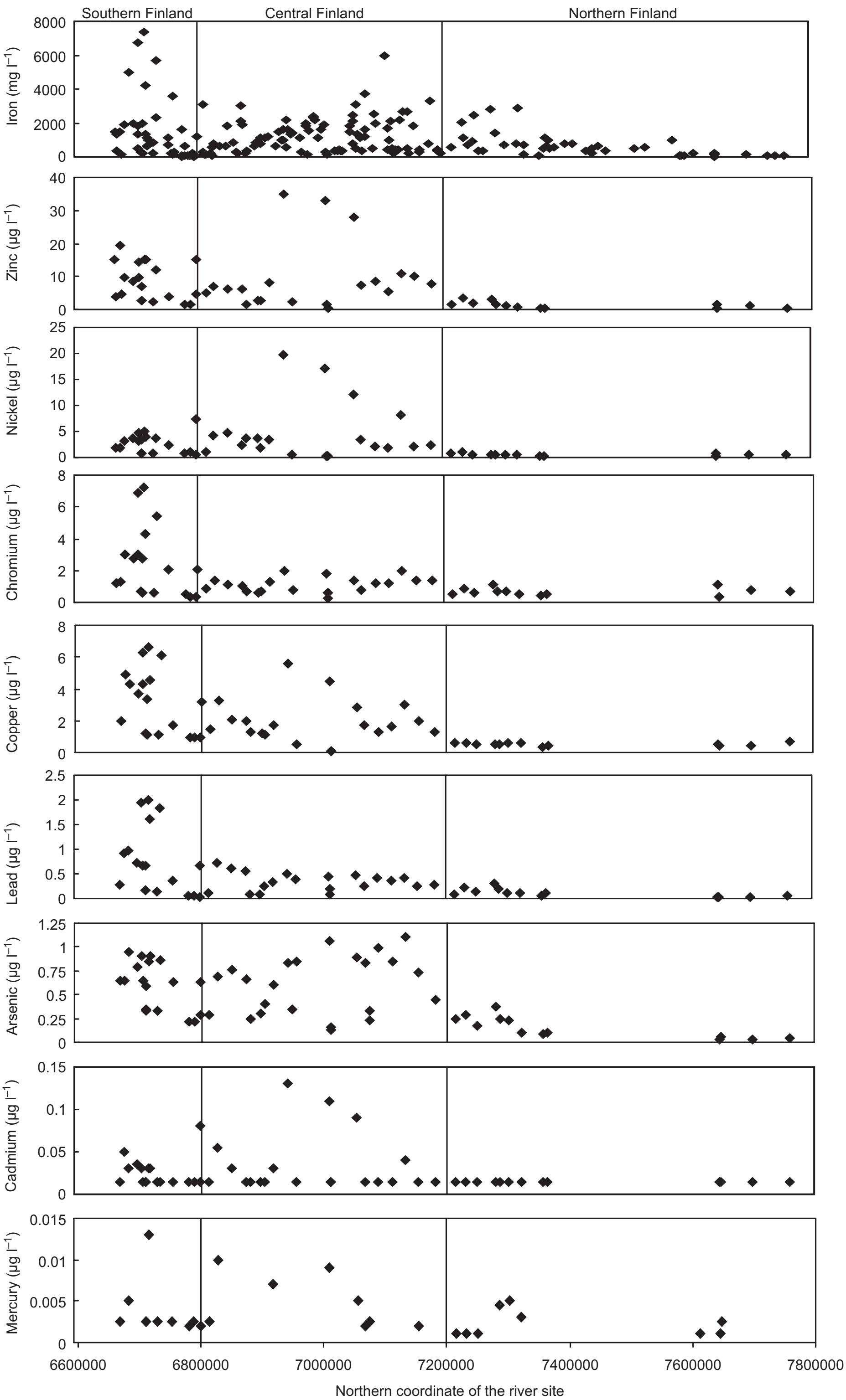

Fig. 4. Median concentrations of trace metals (iron, zinc, nickel, chromium, copper, lead , arsenic, cadmium, and mercury) for the period 1998–2002. Sites arranged as in Fig. 2. Coordinate system as in Fig. 1.

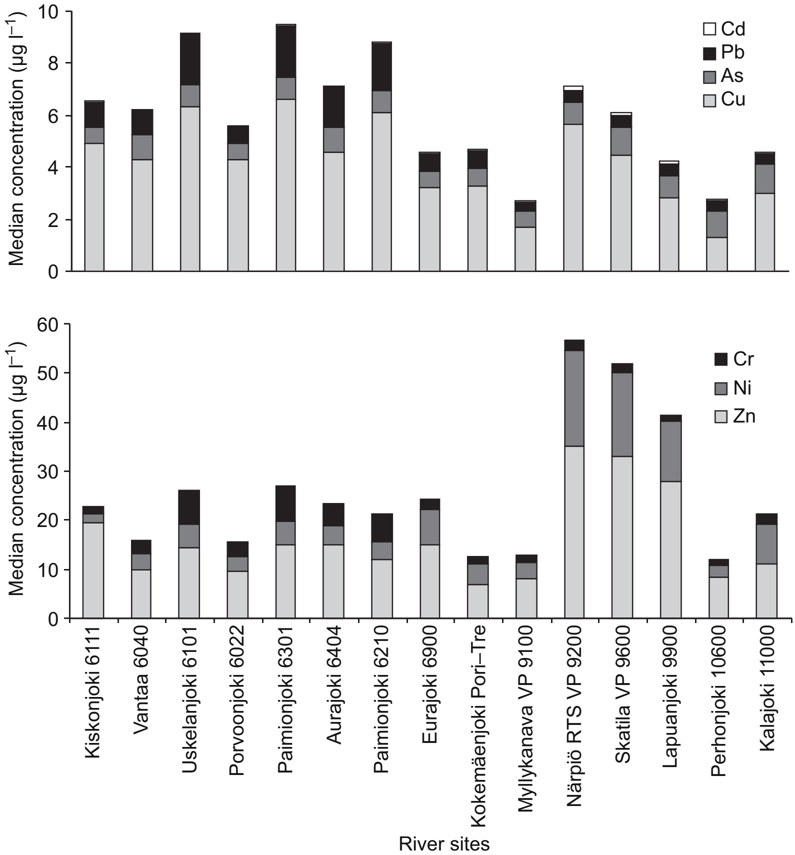

Fig. 5. Highest trace metal median concentrations in 15 river sites, above: cadmium (Cd), lead (Pb), arsenic (As), copper (Cu) and below: chromium (Cr), nickel (Ni), zinc (Zn) for the period 1998–2002.

then five with the highest chromium medians, etc. with each of remaining investigated trace metals. The same river sites appeared several times on this list of 40 rivers. Taking this duplication into account and by deleting duplicates 15 rivers remained. The trace metal medians of these 15 rivers are presented by river sites in Fig. 5. All these 15 rivers with the highest medians are located in the southern, western and south-western part of the country.

Some comparisons are made with the results obtained in a comprehensive study by Tarvainen *et al*. (1997). These authors investigated trace metals in Finnish streams and headwater lakes in 1990, collecting 1165 samples from headwater streams during the environmental geochemical mapping program of the Geological Survey of Finland. The mean sampling density was one sample per 30 km^2 and the number of samples varied between 1147 and 1161. The results revealed an overall picture of trace metal distribution in Finnish streams. Median values of trace metals in streams in their study were (minimum and maximum concentrations in parenthesis): arsenic 0.36 μg l^{-1} (< 0.20–6.5), cadmium < 0.02 μg l^{-1} (< 0.02–1.36), chromium 0.50 μg l^{-1} (< 0.30–6.13), copper 0.64 μg l^{-1} (< 0.10–24.5), nickel μg l^{-1} 0.52 (< 0.20–190.0), lead 0.23 μg l^{-1} (< 0.05–8.78) and zinc 3.57 μg l^{-1} (0.52–301).

According to Tarvainen *et al*. (1997), chromium concentrations tend to be high in brown streams rich in humic material. Zinc concentrations are controlled by acidity and they tend to be elevated in water with low pH. Nickel concentrations in southwestern Finland are probably due to anthropogenic input, whereas anomalies in eastern Finland are correlated with the high nickel content of glacial till. High lead concentrations in the south are probably of anthropogenic origin. The highest arsenic concentrations were in areas with greenstone and arsenic-rich black schists. Copper is common in the industrialized south-west and is of anthropogenic origin. Cadmium is released to the atmosphere from zinc and cadmium refineries, from foundries and from the iron and steel industry. Stream waters with high zinc, copper and arsenic concentrations usually had a large proportion of arable land in their catchments, the source of zinc and copper probably being fertilizers.

In the Eurowaternet rivers most of the median concentrations exceeded the trace metal medians given by Tarvainen *et al*. (1997), particularly in the rivers of southern Finland but often also in central Finland. This is understandable as the rivers investigated by Tarvainen *et al*. (1997) were headwater streams. Many of the elevated medians (e.g. those of zinc, nickel, cadmium and arsenic) were found in the rivers of central Finland, where there are several atmospheric sources of trace metals such as the metal industry and mines, which probably explain the high median values. In the northernmost rivers the medians of trace metals were low. A report of Arctic pollution was published by the Arctic Monitoring and Assessment Programme (1998).

Comparison of Finnish and other Eurowaternet rivers

Water quality of European rivers has been evaluated in the publications of the European Environment Agency (e.g. European Environment Agency 1998, 2005). In these publications comparisons of river water quality have been carried out between the groups of rivers that represent large geographical regions, e.g. the rivers of the Nordic countries have been compared with those of western, central or eastern Europe. Individual rivers have not been compared. Often these comparisons are carried out on the basis of the most important parameters for which comparable data exist, e.g. annual averages of phosphorus, ammonia and nitrate nitrogen, organic matter and trace metals. Direct comparisons of Finnish rivers with other European rivers are difficult to make, because there are different forms to present the data. For example measured water quality parameters vary, methods in aggregating data differ as parameters may be expressed as averages, medians or averaged for the whole year, season, river group or for the whole country etc. Therefore only total phosphorus, cadmium, lead, chromium and copper could be directly compared, although approximate comparisons on a general level are possible.

The rivers of the Nordic countries, including Finnish rivers, are generally of better water quality than other European rivers (European Environment Agency 1998). The lowest phosphorus concentrations were found in the rivers of the Nordic countries, where annual phosphorus averages were below 30 μg l^{-1} in 91% of sites and below 4 μg l^{-1} in 50% of sites. (European Environment Agency 1998). This result reflects nutrient-poor soils, rock layers and low population densities. According to the European Environment Agency (1998) the concentration of total phosphorus in undisturbed rivers is below 25 μg l^{-1}, whereas concentrations above 50 μg l^{-1} indicate human influence.

In the Finnish Eurowaternet monitoring network the median total phosphorus concentration was below the background level (25 μg l^{-1}) in 114 river sites (58%) exceeding 50 μg l^{-1} in 50 sites (26%). This indicates that 26% of the Finnish river sites are influenced by human activities. In the rest of the Europe the number of rivers affected by human influence is generally much higher. Of a total of 1000 river sites in Europe the average total phosphorus concentration was below 50 μg l^{-1} only in about 10% of cases (European Environment Agency 1998). Phosphorus concentrations in European inland waters have developed favourably. The concentrations of total phosphorus have decreased in western Europe and Accession countries in the 1990s, whereas in northern Europe they are close to background values (Nixon *et al*. 2003).

Although the median concentrations of total phosphorus in Finnish rivers are relatively low, in some rivers the concentrations can occasionally be very high. For example total phosphorus concentrations in many rivers of southern Finland are close to the highest values found in the impacted rivers of western and central Europe. This indicates that despite the good overall water quality, many of the investigated Finnish rivers are under pressure and are affected by anthropogenic factors. Effective and continuous measures of water quality management are therefore also needed in the future.

The European Environment Agency (1998) compared the average values of cadmium, lead, chromium and copper in some European rivers. The concentrations in relatively unpolluted rivers were: cadmium 0.03–0.1 μg l^{-1}, lead 0.1–5.8 μg l^{-1}, chromium 0.5–1.0 μg l^{-1} and copper 0.7–1.3 μg l^{-1}. In relatively polluted rivers the concentrations were: cadmium 0.2–0.5 μg l^{-1}, lead 3–30 μg l^{-1}, chromium 5–10 μg l^{-1} and copper 4–10 μg l^{-1}. The Finnish rivers included in the comparison had the following concentrations: cadmium 0.03 μg l^{-1} (about the same as the median concentration of the rivers in the Finnish Eurowaternet), lead 0.1 μg l^{-1}, chromium 0.5 μg l^{-1} and copper 0.7 μg l^{-1} (all three lower than the median concentrations of the rivers in the Finnish Eurowaternet in southern and central Finland; Fig. 4).

The average of country average concentrations in 1990–1995 given by the European Environment Agency for rivers of a group of western European countries were for cadmium about 0.1–0.2 μg l^{-1} and for mercury about 0.1–0.14 μg l^{-1}. In the Nordic rivers the cadmium concentration was about 10% of these values and that of mercury only about 1%. These preliminary comparisons indicate that the trace metal concentrations in Finnish Eurowaternet rivers are lower than in those of the rivers of western and central Europe.

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References

Arctic Monitoring and Assessment Programme (AMAP) 1998. *Assessment report. Arctic pollution issues. Arctic monitoring and assessment programme*. Oslo, Norway.

Ekholm P. & Mitikka S. 2006. Agricultural lakes in Finland: Current water quality and trends. *Environmental Monitoring and Assessment* 116: 111–135.

Eloranta P. (ed.) 2004. *Inland and coastal waters of Finland*. Proceedings of the XXIX SIL Congress, Lahti, Finland, 8–14 August 2004, University of Helsinki.

European Environment Agency 1996. *European freshwater monitoring network design*. Topic report 10/1996, EEA, Copenhagen.

European Environment Agency 1998. *Europe's environment: The second assessment*.

European Environment Agency. 2005. *The European environment — state and outlook 2005*.

European Parliament and Council Directive 2000. Directive 2000/60/EC of the European Parliament and of the Council establishing a framework for Community action in the field of water policy. *Official Journal of the European Communities* 43: 1–72.

Finnish Environment Institute 2005a. *CORINE land cover 2000*. Finnish Environment Institute.

Finnish Environment Institute 2005b. *Water quality of lakes, rivers and sea areas in Finland in 2000–2003*. Finnish Environment Institute, Helsinki, Finland.

Kauppila P. & Koskiaho J. 2003. Evaluation of annual loads of nutrients and suspended solids in Baltic rivers. *Nordic Hydrology* 34: 203–220.

Mitikka S. & Ekholm P. 2003. Lakes in the Finnish Eurowaternet: status and trends. *The Science of the Total Environment* 310: 37–45.

Mitikka S., Britschgi R., Granlund K., Grönroos J., Kauppila P., Mäkinen R., Niemi J., Pyykkönen S., Raateland A. & Silvo K. 2004. *Report on the implementation of the Nitrates Directive in Finland 2004*. Finnish Environment 741, The Finnish Environment Institute.

Niemi J.S. 1998. The quality of river waters in Finland. *European Water Management* 1: 36–40.

Niemi R.M. & Niemi J.S. 2000. Monitoring of faecal pollution in Finnish surface waters. In: Heinonen P., Ziglio G. & Van der Beken A. (eds.), *Hydrological and limnological aspects of lake monitoring*, John Wiley & Sons Ltd., pp. 143–156.

Niemi J. (ed.) 2006. *Environmental monitoring in Finland 2006–2008*. Finnish Environment 26, Finnish Environment Institute.

Niemi J.S., Heitto L., Niemi R.M., Anttila-Huhtinen M. & Malin V. 1997. Bacteriological purification of the Finnish River Kymi. *Environmental Monitoring and Assessment* 46: 241–253.

Niemi J., Heinonen P., Mitikka S., Vuoristo H., Pietiläinen O.-P., Puupponen M. & Rönkä E. 2001a. The Finnish Eurowaternet. *European Water Management* 4: 47–53.

Niemi J., Heinonen P., Mitikka S., Vuoristo H., Pietiläinen O.-P., Puupponen M. & Rönkä E. 2001b. *The Finnish Eurowaternet with information about Finnish water resources and monitoring strategies*. The Finnish Environment 445, Finnish Environment Institute.

Niemi J., Lepistö L., Mannio J., Mitikka S. & Pietiläinen O.-P. 2004. Quality and trends of inland waters. In: Eloranta P. (ed.), *Inland and coastal waters of Finland*, XXIX SIL Congress, Lahti, Finland 8–14 August 2004, University of Helsinki, pp. 18–40.

Nixon S., Trent Z., Marcuello C. & Lallana C. 2003. *Europe's water: an indicator-based assessment*. Topic report 1/2003, European Environment Agency, Copenhagen.

Pietiläinen O.-P. 1997. Agricultural phosphorus load and phosphorus as a limiting factor for algal growth in Finnish lakes and rivers. In: Tunney H., Carton O.T., Brookes B.C. & Johnston A.E. (eds.), *Phosphorus loss from soil to water*, CAB international, Wallingford, UK, pp. 354–356.

Pitkänen H. 1994. Eutrophication of Finnish coastal waters: Origin, fate and effects of riverine nutrient fluxes. *Publications of the Water and Environment Research Institute* 18: 1–44.

Räike A., Pietiläinen O.-P., Rekolainen S., Kauppila P., Pitkänen H., Niemi J. & Raateland A. 2003. Trends of phosphorus, nitrogen and chlorophyll-a concentrations in Finnish rivers and lakes in 1975–2000. *The Science of the Total Environment* 310: 47–59.

Tarvainen T., Lahermo P. & Mannio J. 1997. Sources of trace metals in streams and headwater lakes in Finland. *Water, Air and Soil Pollution* 94: 1–32.

Vuoristo S. 1998. Water quality classification of Finnish Inland waters. *European Water Management* 1: 35–41.